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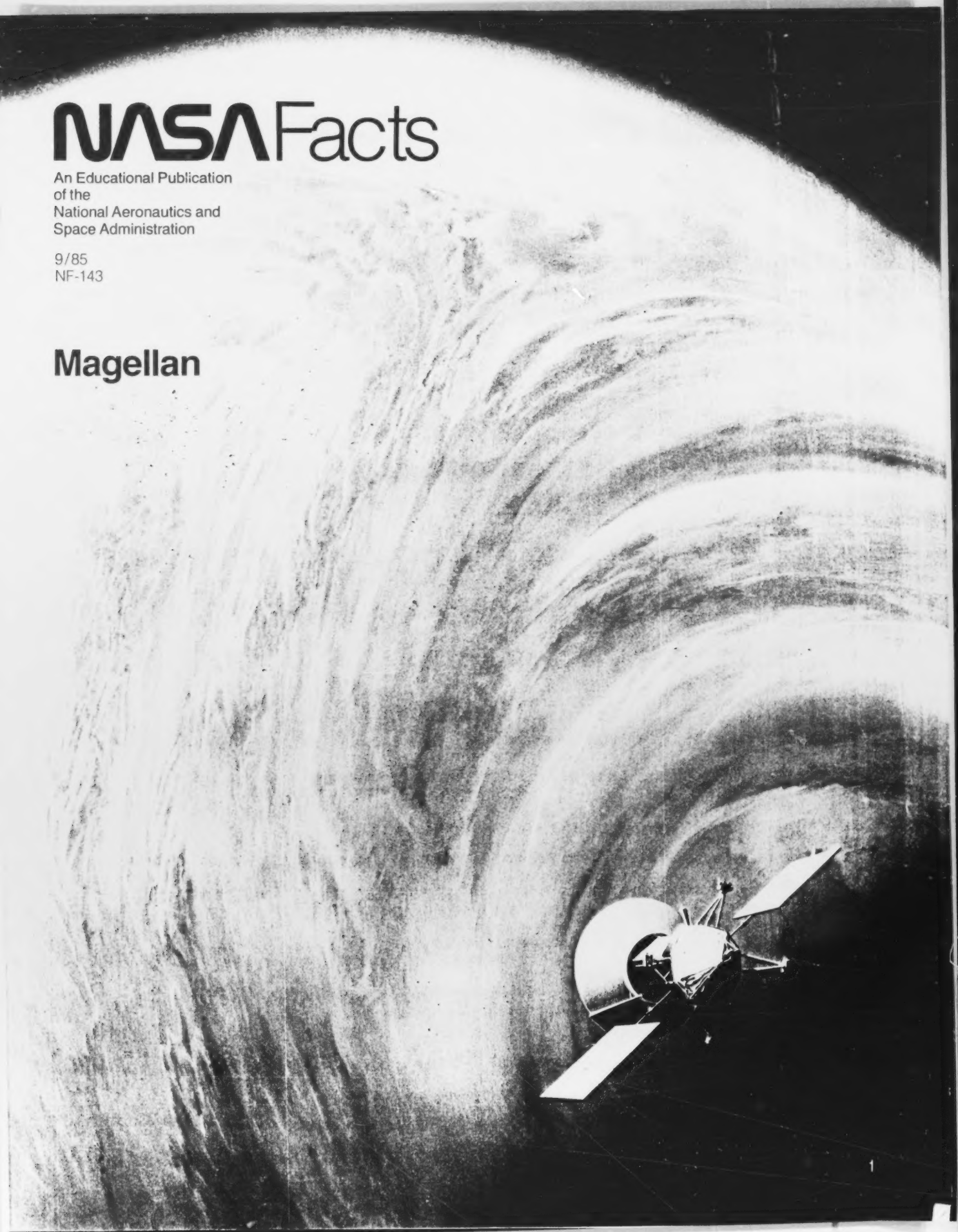
Magellan



Of all the planets in the solar system, Venus is the most like our own Earth in size, mass, and distance from the Sun. The motions of our planetary "twin" were known to the ancients, and its apparent changes in shape, similar to the phases of the Moon, were first studied by Galileo more than four centuries ago. In the modern era, it is by far the most visited world in the solar system—more than 20 spacecraft from the Soviet Union and the United States have been sent there since the early 1960's. The clouds of Venus have been probed, the structure and composition of its atmosphere measured, its landscape photographed, and its rocks chemically analyzed by automated landers.

Yet, for all our fascination with Venus, we have only a sketchy, general knowledge of the planet's surface. While the other three "terrestrial" worlds—Earth, Mercury, and Mars—have long since been mapped, details of the face of Venus are still largely unknown, due to the planet's dense, constant cloud cover. The clouds prevent us from ever photographing the solid surface, even from space, with conventional cameras.

Beginning in the early 1960s, scientists on Earth began to counter this problem by using radar waves, which, unlike visible light, are able to penetrate the Venusian clouds and reflect off the solid planet back to Earth. With the help of computer processing, these radar reflections can be turned into pictures of the Venus surface. Earth-based radar imaging is thus extremely valuable, but it also is limited—Venus always shows the same hemisphere to us when it is near enough in its orbit for high-resolution study, so only a fraction of the planet can be explored from Earth.

In 1978, NASA launched the Pioneer Venus spacecraft to conduct the most thorough investigation of Venus ever undertaken. Most of the experiments concerned the planet's atmosphere, but the spacecraft also carried a radar system that mapped 92% of the surface from Venus orbit with a resolution (a measure of the smallest objects that can be seen in its map) of about 100 kilometers (km) (60 miles). For the first time, planetary scientists had a global map of Venus that showed the existence of its continent-like highlands—Aphrodite and Ishtar—its hilly plains, the large, volcano-like mountains of Beta Regio, and the flat lowlands.

Five years after Pioneer, in 1983, the Soviet Union sent two Venera spacecraft to map Venus at a resolution of approximately 2 km. Because of the nature of their orbits around the planet, they were only able to map about 30% of the surface near the north pole. Although the Venera 15 and 16 images have answered some of our questions about Venus, many more remain unanswered. And the Pioneer Venus radar map, as important as it is, shows only large-scale features. The hills and valleys, craters and lava flows—the telling details of Venus geology—are as yet uncharted.

In April 1988, NASA plans to launch the Magellan spacecraft from the space shuttle. It will arrive at Venus in July 1988 to begin an eight-month mission that will map more than 90% of the planet with a resolution more than 100 times better than that of Pioneer Venus, and nearly ten times better than any views of the surface taken since that time. More than any other single mission, Magellan is expected to unveil the secrets of the Venusian past, just as Mariner 9 revealed the unsuspected richness of Martian geology in 1972. In 1988, for the first time, we will come to know the face of our planetary "twin."

The Spacecraft

A key feature of the Magellan mission is the economy and relative simplicity of its design. To save costs, hardware was borrowed from other planetary programs, notably Voyager and Galileo. The 975 kilogram (2150 pound) spacecraft has only one science instrument: a radar system used for imaging, for altimetric profiling of the planet's topography, and for measuring radiation from the Venus surface. Magellan's only moving parts are a pair of 5.8 meter panels that collect solar energy for charging the spacecraft's nickel-cadmium batteries. These will turn around their axes during the mission to follow the Sun without the spacecraft's having to rotate.

Magellan's large, 3.7 meter (12 ft.) high-gain antenna dish (used for radar imaging and for communicating with Earth) and the spacecraft "bus" containing electronics subsystems were both acquired from a spare Voyager spacecraft. The computers used for commanding, handling data, and attitude control will create the high resolution pictures required for the Magellan mapping mission. Synthetic Aperture Radar (SAR), however, relies on a different principle to form its image. By combining successive radar returns taken while the surface of Venus passes through the beam of the antenna, the radar system will be able to electronically reproduce the resolution of a larger antenna. This "aperture synthesis" is what gives SAR its power as well as its name.

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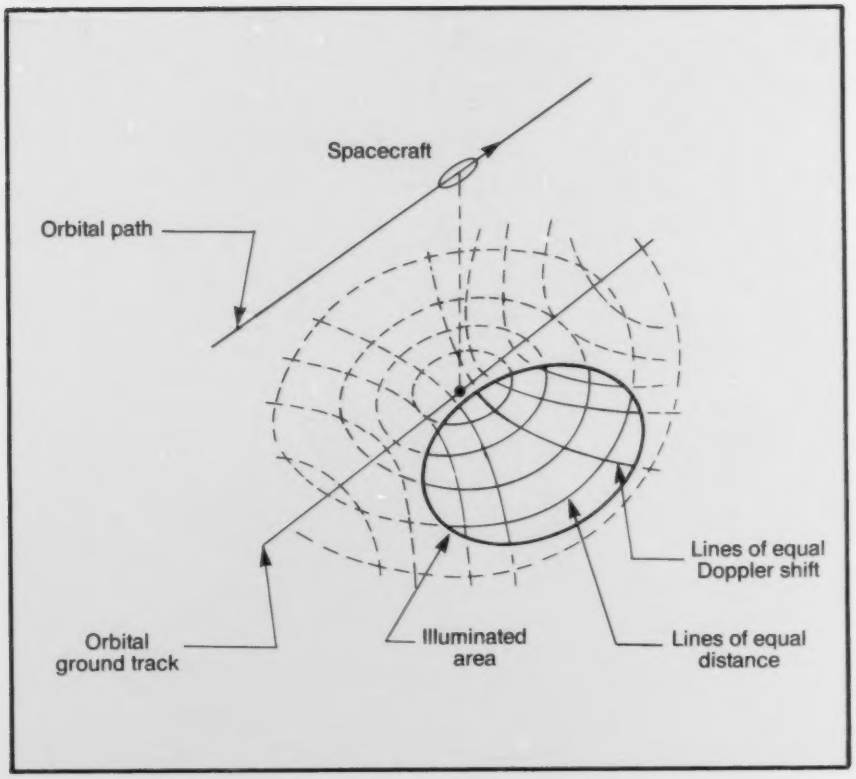

How Synthetic Aperture Radar (SAR) works: Any point in the radar map image can be located by using two coordinates — the distance to the point (determined by the time delay of the returning signal), and the amount of Doppler shift in the signal. The SAR antenna "looks" to one side of its orbital path to distinguish right-side from left-side signals.

As Magellan passes over the surface of Venus, its dish antenna will look downward and to the side of the spacecraft's orbital path. The SAR antenna will illuminate an area 25 km (15 miles) wide with rapid radar pulses, then record the returning signals. Each point on the planet's surface can then be located by using two coordinates. First, a measurement of the time it takes for the radar signal to return to Magellan will give the spacecraft's distance to that point. Second, a careful measurement of the Doppler shift of the returned signals will give the location of the point with reference to the spacecraft's line of flight, since Magellan will either be approaching or receding from the point at any given time. (Doppler shift is a change in wavelength caused when an object is moving relative to a wave source. A familiar example is the apparent change in pitch of a car horn or a train whistle as it moves toward or away from you. Waves from an approaching source are bunched together and made shorter. When the source is receding, the waves are stretched out and become longer.)

Since each point in the radar image will have a unique Doppler shift and range, these two coordinates and a knowledge of the angle of the antenna's line of sight with respect to the surface are all that are needed to get a fix on the location of any returned signal. The brightness of the image at that point then becomes an element of the map image.

Using this technique, data will be collected by the radar instrument and radioed back to Earth, where images of the Venusian surface will be constructed by computers. The images will have a radar resolution of about 120 meters for the equatorial regions of the planet (where Magellan will pass closest to the surface) and about 190 meters near the poles. In these radar photographs, it will be possible to distinguish features as small as 250 meters on the surface. By comparison, the best existing ground-based and spacecraft maps of Venus show no features smaller than 1 or 2 km.

April 1988: From Earth to Venus

In April, 1988, Magellan will be carried into low Earth orbit by the space shuttle, then launched from the shuttle's cargo bay into its own orbit with an upper stage Centaur G rocket motor attached to its base. After several revolutions around the Earth, the Centaur rocket will fire to boost the Magellan spacecraft toward Venus.

The target date of April, 1988 is not arbitrary, but is timed so that Magellan can travel an orbit joining Earth and Venus that requires a minimum amount of fuel. The period of launch opportunity lasts for 20 days, beginning April 6. Venus during that time will be approximately 90 million km (56 million miles) from Earth, and it will take just under four months for Magellan to reach its destination. Trajectory correction maneuvers along the way will keep the spacecraft on time and on target.

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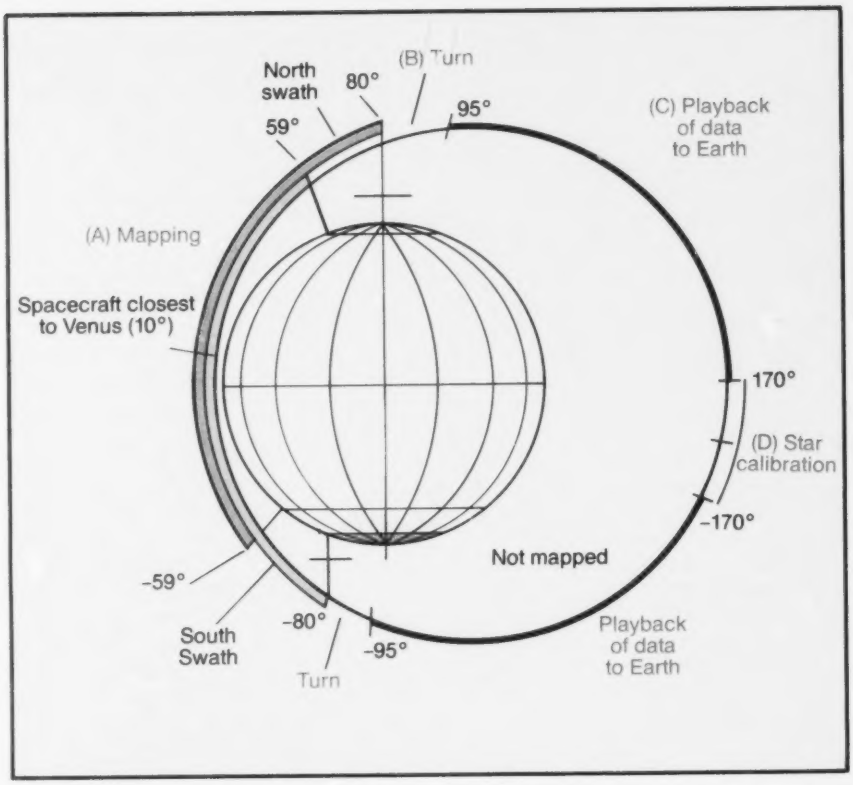
When it arrives at Venus in late July, a solid rocket motor attached to the spacecraft will fire to place Magellan in orbit around the planet. After a few adjustment maneuvers, Magellan will be in a highly elliptical orbit, with its lowest point 300 km (185 miles) from the surface and its high point at an altitude of 7,762 km (4,823 miles). The time required for Magellan to make one complete orbit around Venus—the orbit period—will be 3.1 hours. Since the orbit will be tilted five degrees to the axis of Venus, the spacecraft will pass nearly, but not quite, over the north and south poles.

Although Venus is very much like the Earth in size and mass, there are a number of peculiarities about the planet's rotation on its axis. One is that it turns in the opposite direction from Earth, spinning on its axis from east to west instead of west to east. Another is that the Venusian "day" is very long—it takes 243 of our Earth days for the planet to make one rotation. (Strangely, it takes only 224 days for Venus to make one complete orbit around the Sun: the Venusian "day" is longer than the Venusian year.) Magellan will be in a fixed polar orbit around a very slowly turning globe, and since it will take 243 days for every point on the surface to pass under its gaze once, the mapping operations are planned to take exactly 243 days.

The target date for arrival at Venus is July 26, 1988. This will place Magellan in Venus orbit in time to finish its mapping mission before superior conjunction (the lining up of the planet behind the Sun as seen from Earth), during which time there would be too much disturbance to radio communications to conduct spacecraft operations.



The 3.1 hour orbit of Magellan is divided into distinct phases. When the spacecraft is closest to Venus, the radar antenna maps the surface (A), alternating between north and south swaths on successive passes. After radar operations are completed, the antenna is turned to point toward Earth (B) so that data can be transmitted (C). After a period of calibrating the spacecraft's navigational system (D) and another data playback, Magellan turns its attention once again to the surface.

When Magellan's elliptical orbit brings it close to the surface of Venus, the radar instrument will look through the clouds to map the solid planet. Most of the rest of the time will be spent transmitting data back to Earth.

Mapping the Veiled Planet

Circling the planet every 3.1 hours, Magellan will pass closest to the surface just north of the equator at 10 degrees Venus latitude, then will move up over the north pole and around the planet in a wide loop. As a result of this elliptical orbit, Magellan will only be close enough to the surface to conduct mapping operations for about 35 minutes out of each three-hour orbital period. The rest of the time will be spent transmitting the raw data from the just-completed mapping pass and receiving telemetry instructions from Earth, or calibrating the spacecraft's navigation and guidance system with reference stars.

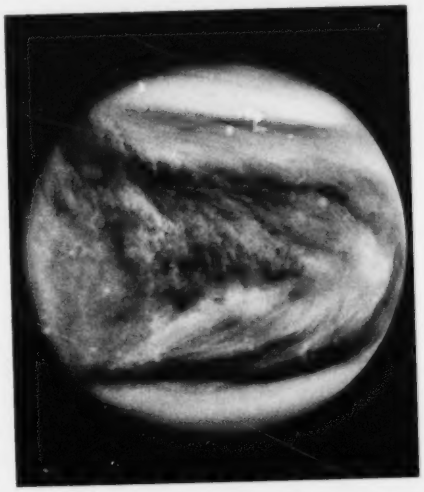
During mapping operations, the high-gain antenna dish will point down at the surface of Venus. In addition to taking radar imaging data, the radar system will use a separate horn antenna aimed at the surface directly beneath the spacecraft for Magellan's altimetry experiment. Radar pulses from this fan-beam horn antenna will bounce off the surface and return to the radar receiver. By measuring the

time it takes for the signal to return, the altimeter will determine the distance to the point directly below the spacecraft, and so will construct a topographic profile of the planet in much the same way that sonar is used onboard ships to profile the ocean floor. By mission's end, the Magellan altimeter experiment will have produced a topographic map showing height variations as small as 30 meters for the entire mapped part of the planet.

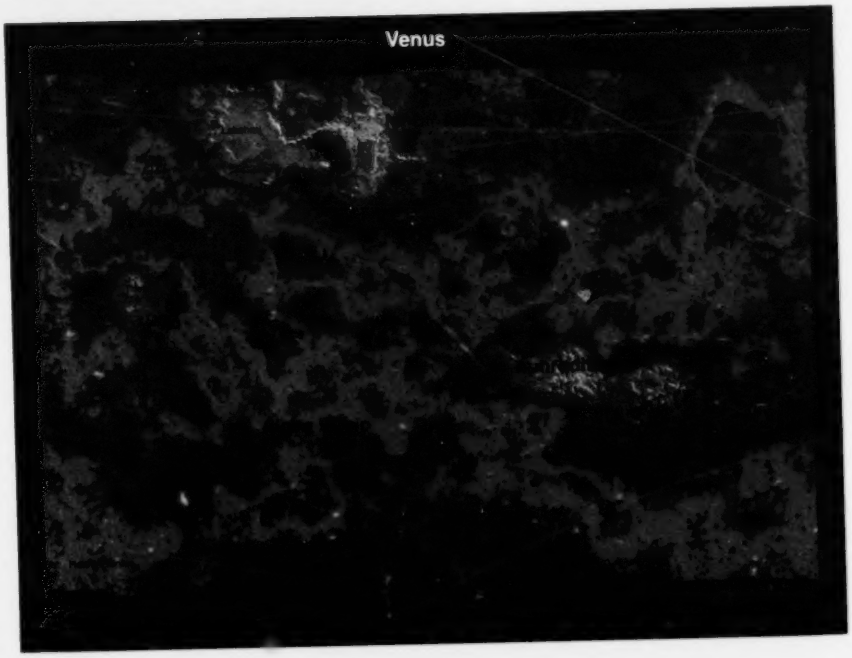
Several additional types of information can be gleaned from Magellan. When the dish antenna is pointing down at the planet, it will be used to measure the amount of radiated thermal microwave energy, which will show temperature variations on the surface. Analysis of the way in which the radar signals are reflected from the surface will yield information on the electrical conductivity and composition of the Venusian rocks. Also, when the spacecraft is in radio communication with Earth, ground trackers will be able to analyze slight changes in its orbital path to detect variations in Venus' gravitational field, which provide important clues to the makeup of the planet's interior.

Because the same antenna used for mapping is also used for radio communications, the spacecraft must re-orient itself to transmit data back to Earth. After each mapping sequence, the spacecraft will look away from Venus so that data from the just-finished mapping sequence can be beamed Earthward. The transmissions will be received by the large antennas of the Deep Space Network located at various sites around the world, then relayed to the Jet Propulsion Laboratory in Pasadena, California. Just about the time this "call home" is completed, the spacecraft will come into position to begin another mapping pass, and will again point down toward the surface.

As Magellan orbits the slowly turning planet, the surface will be mapped in successive, overlapping strips. Each strip, or swath as it is called, will be about 25 km (15 miles) wide and about 16,000 km (9,942 miles) long. Closer to the north pole, where successive swaths will naturally converge, there is no need for all of them to overlap, so an alternating pattern of northern and southern mapping passes will be used (Figure X). On one pass, the radar will begin mapping in southern latitudes and continue all the way to the north pole. Then, on the next pass, the mapping swath will begin farther south, and will end before reaching the pole. In this way, all of the mapping strips will overlap in middle latitudes to ensure complete coverage near the equator, and every other strip will overlap near the poles to give full coverage at higher latitudes. These image strips will then be combined by computers on Earth into photomosaic images covering large parts of the Venus surface.



Sweltering under a perpetual cloud cover, Venus reveals no surface details even in ultraviolet light (A), but a radar instrument on the Pioneer Venus orbiter was able to disclose for the first time the large-scale geography of the planet (B). Blue areas represent the planet's lowlands, while highlands are green and yellow in this false color map.



Venus' largest elevated landmass, Aphrodite, has two major mountain regions on opposite sides of the "continent." In addition to the rough mountainous regions, Aphrodite also has the lowest elevations on Venus —in the trenches of Diana Chasma, which may be a rift valley caused by crustal extension.

Magellan's elliptical orbit makes it impossible to obtain full coverage of both poles during the course of a 243 day mission, so mission designers had to choose whether the northern or southern hemisphere would be fully mapped. Because the large "continent" of Ishtar, which seems to have a number of significant geologic provinces, appears on Pioneer Venus maps to extend into high northern latitudes, it was decided to provide full coverage of the northern hemisphere; mapping coverage of the southern hemisphere will extend to about −67 degrees latitude.

Thus, about eight times each day, for 243 days, Magellan will take radar images of the surface of Venus, with the result that, by project's end, approximately 90% of the planet will have been mapped.

The Planet Venus

Although the Earth and Venus have very similar bulk properties, there are important differences between the two planets. They are most likely made of the same type of silicate rock, and their interiors are probably similar, but Venus does not appear to have a magnetic field as Earth does. Venus is closer to the Sun than we are, and receives almost twice as much solar radiation. Both planets have atmospheres. The Venusian atmosphere, however, is much denser than our own, and is composed almost

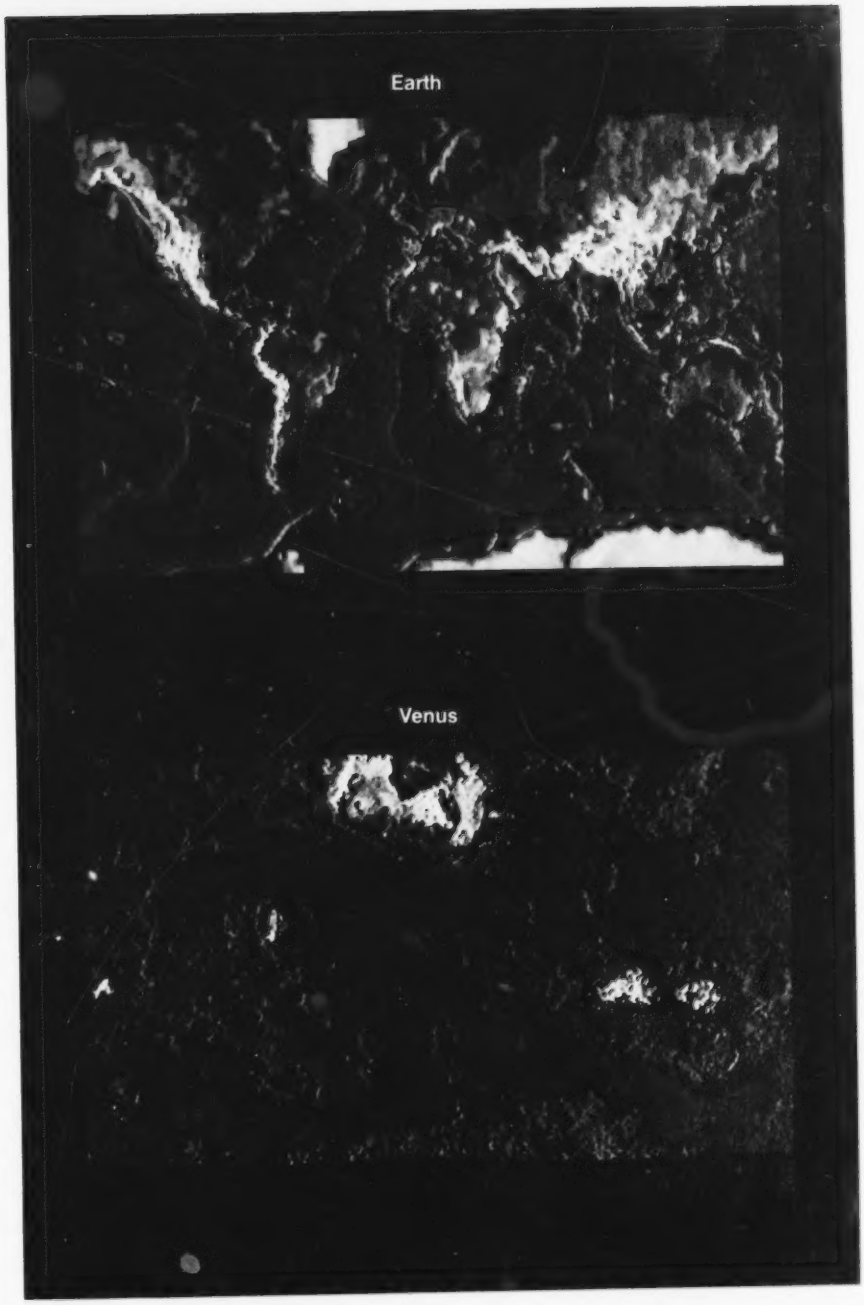
Venus-Ishtar Terra
Cleopatra Patera
Maxwell Montes
Freyja Montes
Lakshmi
Sacajawea
Planum
Colette
Akna Montes
Vesta Rupes
Ut Rupes

A portion of the "continent" of Ishtar is shown in this computer-processed Pioneer Venus image. At the center is Mt. Maxwell, taller than Mt. Everest, and believed to be an active volcano. The Lakshmi plateau, rising 4-5 km above the mean level of Venus, is bordered by mountain ranges to the north and northwest. The plateau is believed to consist of thin lavas overlying an uplifted section of older crust. Soviet Venera radar data suggest that the depression called Colette is a collapsed volcanic crater. On Ishtar's southern flank are the Ut and Vesta cliffs, which descend to vast lowlands.

entirely of carbon dioxide, with a high-altitude covering of clouds composed of sulfuric acid. It is this thick blanket of carbon dioxide that traps incoming thermal radiation between the solid planet and the atmosphere and makes Venus a perpetual furnace, where surface temperatures reach 480C (900F) and the atmospheric pressure is 90 times that of Earth. Any water that might have once existed has long since disappeared: Venus today is bone-dry.

We know some things about Venusian geology from past space probes and from Earth-based radar studies. Soviet Venera lander photos and chemical analysis experiments performed on the surface have shown that the rocks of the highland areas near the landers are heavy and basaltic, like the rocks of Earth's ocean floor or the rocks that form from oozing volcanic lava flows.

The large-scale geography of the planet has been disclosed by radar studies from Earth, and more fully, by the Pioneer Venus Orbiter in 1978. Most of the planet consists of either rolling upland plains (these are apparently composed of older crustal rock) or smooth lowland areas. There are two major continents, or elevated plateaus—Aphrodite, named for the Roman equivalent of the goddess Venus, and Ishtar, named for the Babylonian equivalent—that appear to be younger geologically. Ishtar is about



Only very general conclusions about the geology of a planet—Venus or Earth—can be drawn from radar images with the resolution obtained by Pioneer Venus. The more sensitive Magellan spacecraft will give scientists a better understanding of processes that have shaped the surface and the interior of Venus.

the size of Australia; Aphrodite is about twice as large, or approximately the same size as South America. Jutting up from the Ishtar highlands is one of the highest mountains in the solar system, 10,800 meter-high (35,400 ft) Mount Maxwell, which is most likely an active volcano. Two other highland areas of apparent volcanic origin, Alpha Regio and Beta Regio, also stand out conspicuously on the Pioneer Venus map.

The Earth and Venus: Twins?

Some 4.6 billion years ago, the planets of the solar system condensed as large, individual knots in a whirlpool of solid material revolving around the Sun. Heavier elements like iron and silicon remained in the inner solar system to form the rocky planets Mercury, Venus, Earth, and Mars. The lighter gasses—hydrogen and helium—went to form the giant planets beyond the asteroid belt. The largest rocky planet, Earth, was extremely hot in those millennia after it condensed into a tight ball, and in its early history the planet shed heat through great violent volcanoes that covered its surface. The Earth still sheds heat today, but now on a low simmer, with isolated chains of volcanoes spewing hot material from the interior.

The Earth's upper crust is divided into pieces—tectonic plates—that move around the planet's curved surface, driven by convection cells in the hot fluid rock underneath the solid crust. One of the most important questions for the study of Venus is whether a similar process of plate tectonics has shaped the surface of our planetary "twin." Virtually all of the large-scale features of the Earth, including the mountain chains and the ocean basins, are a result of the movement of these plates. When continental plates collide, mountains such as the Himalayas and the Alps are thrust upward. Where the plates pull apart, rift valleys and ocean basins form. Earthquakes and volcanoes, the major geologic upheavals on our planet, occur primarily at plate boundaries where pieces of the crust are stretching apart or crunching together.

Although we might logically expect Earth's "twin" to have similar processes shaping its surface, we have yet to see evidence of planetwide plate tectonics on Venus. On Earth, where plates are pushing away from each other in the middle of the Atlantic Ocean, there is a volcanic ridge thousands of kilometers in length where a great deal of the planet's internal heat is vented. No such conspicuous plate boundaries appear in the Pioneer Venus map, however, suggesting that if a system of plate tectonics does exist on Venus, it must be of a different kind than Earth's. (It should be noted, though, that evidence of plate tectonics on our planet would only be marginally visible at the resolution of Pioneer.)

Questions For Magellan's Exploration of Venus

Volcanoes

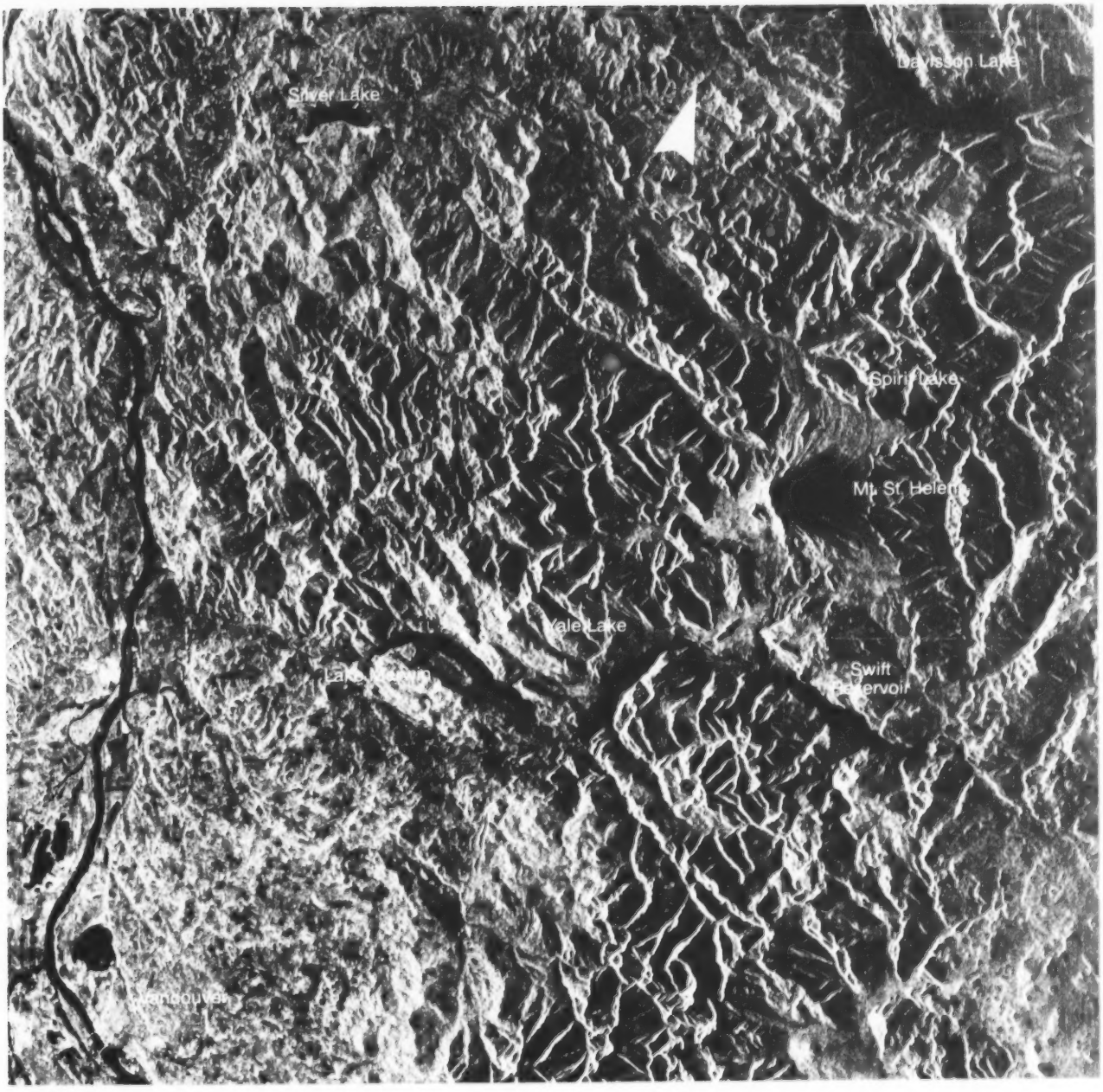
One of the most important tasks for Magellan during its mapping mission will be to take an inventory of volcanic craters on the Venusian surface so that scientists can reconstruct the planet's geologic history. Ground-based and Venera radar images have shown the existence of volcanic craters on the Ishtar plateau. Electrical discharges detected by the Pioneer Venus spacecraft in the clouds above Mt. Maxwell, high concentrations of sulfur dioxide in the atmosphere, and other data suggest that Maxwell may be an active volcano, possibly one of many still active on Venus. By counting how many volcanoes are on Venus' surface and showing where and what kind they are, Magellan will provide data on the planet's internal processes.

The radar images should be able to discriminate between successive, overlapping lava flows so as to determine the sequence of volcanic events that shaped the surface. By examining the slopes and shapes of these volcanic flows, it also will be possible for scientists to make judgments about the composition of the lava, which again gives clues about the makeup of the planet's interior and the thickness of the crust.

Earlier spacecraft data have shown that the gravitational field of Venus is strongest over the planet's elevated plateaus—further evidence that young, volcanic rocks are being piled up in these highland areas. Magellan's gravity survey will collect more information on this correlation between gravity and topography.

Impact Craters

Meteorite impact craters also appear in radar images of Venus, and another major task for Magellan will be to distinguish these impact scars from volcanic craters and to take count of how many are still preserved on the surface and where they exist. This is an important point to establish, since the more cratered a surface is, and the larger the craters it contains, the older it is likely to be. Earth's surface, for the most part, is young and uncratered. Although meteorites have struck our planet in the past, the evidence has been erased by wind and water erosion and by the constant motion of tectonic plates through time—the surface of Earth is a slate that has been drawn on, wiped clean, and reworked again over millions of centuries. Venus, on the other hand, appears to retain evidence of a comparatively distant past. Magellan's global inventory of craters should have much to tell scientists about the



This processed Synthetic Aperture Radar (SAR) image of the Mt. St. Helens region of Washington was taken by the SEASAT oceanographic satellite. Magellan's SAR instrument will return radar images of Venus with comparable resolution.

planet's history and the age of different geologic provinces. The rate of surface cratering will also provide information on how dense the planet's atmosphere has been through time.

At the best resolutions obtained to date, it is unclear whether certain circular features seen on Venus are the scars of old impacts, or whether they are collapsed remnants of volcanic craters or domes of rock somehow warped upward by tectonic forces. Magellan's resolution should help clear up the mystery. If the radar images show large stretches of old, cratered terrain, it would argue against tectonic motion in those regions, since compression or extension of the crust would destroy old craters. It would also indicate that the processes of erosion proceed much more slowly on Venus than on Earth.

Faults, Ridges, and Mountains

There evidently is some kind of crustal movement at work on Venus, because mountain-like folded ridges and rift-like valleys appear in radar images of Ishtar Terra. These features are most probably caused by the compression or extension of the crust. Magellan will reveal the details of these features, allowing scientists to characterize how Venusian tectonics work. It has been proposed that the high surface temperatures on Venus play a part in the distortion of the crust, and Magellan will provide new data to test that theory. Large rift valleys such as Devana Chasma in Beta Regio will be scrutinized to see whether they were formed by volcanic processes or by tectonic motion.

Water and Wind

Another critical question about Venus is whether it once had water on its surface. Modern-day ratios of deuterium to hydrogen in Venus' atmosphere suggest that at some point in the past there was more water in the planet's atmosphere. Magellan will be looking for evidence of ancient marine terraces, river channels and deltas, or other geologic features that might point to the existence of ancient oceans. This would have profound implications for the evolution of the planet's atmosphere as well as its surface. Although the most recent Venera radar pictures have shown no signs of large-scale erosion by wind on Venus, and surface winds there are believed to be slower than on Earth, there may be large windblown dunes on the surface that would show up in high resolution Magellan images.

The Venera spacecraft have inspected less than one third of the surface of Venus at high resolution. Over the course of one Venusian year, Magellan will map nearly the entire globe with ten times the detail of these best previous spacecraft images, and will reveal, if they exist, signs of volcanic, wind, water, and meteorite impact forces: in short, all the processes that dictate a planet's history and shape its face. By doing that, the Magellan mission should help to answer the question of why Venus, our planetary "twin," is at the same time so much of a stranger.

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